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Utilization of waste heat from exhaust gases of gasoline generator for water heating

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ABSTRACT

This work presents the application of waste heat from exhaust gases of gasoline generator through a heat exchanger for household water heating. Two cases were experimented. First, was when water was supplied and filled the heat exchanger without discharging through the tap (retained). Second, was when water was continuously supplied to the heat exchanger and continuously discharged through the tap. In both cases, the temperatures of water and exhaust gases were measured. Measurement showed that during one hour of operation, the water temperature increased from 30⁰C to 63⁰C in the first case and from 28⁰C to 49⁰C in the second case. The average mass flow rate of water in the first case, average mass heating rate of water in the second case and average mass flow rate of exhaust gas in the first and second cases were determined to be 0.01 kg/s, 0.044 kg/s, 0.02 kg/s and 0.09 kg/s respectively. The heat gain rate of water in first and second cases were determined to be 1.28 kW and 22.58 kW respectively.

1. INTRODUCTION

Conservation of energy is paramount as a result of the need to mitigate the wide gap that prevails between the demand and supply of energy [1]. With the perpetual need of energy by humans, it has become imperative to have an increase in energy production and reduction in its consumption in order to forstall its unsupportable longstanding balance [2]. The various types of internal combustion engine used as prime movers or for electricity generation give out heat along with their exhaust gases [3] and this heat is undoubtedly wasted [4]. The waste heat is in the range of 55-75% of its total energy contained in the fuel [2] and more than 30% of combustion heat is carried away by the exhaust gases [1, 5-7]. If a fraction of the waste energy is reclaimed by the system, it will result in an inrease in efficiency and reduction in emissions of the engine [7-8].

In most cases, this waste heat is not used. However there are great investments in the technology of waste heat use so as to promote reduction in cost of use of energy [9]. Waste heat recovery system is simply the reclaiming of heat contained in fluids of systems like internal combustion engines; heat that can be converted to other forms of energy that would have been lost[10]. Although waste heat has been used for electricity generation [11-15], mechanical work [16] and vapour absorption refrigeration system, it can be employed for heating water for domestic use. The reason is that the main area where energy is highly consumed in living homes is water heating [10]. Forty percent of electricity used in homes is for water heating [17]. Cooking, processing and domestic appliance cleaning requires the use of hot water [17]. To meet with these reqirements, hot water is produced by the use of electricity which is expensive or burning fossil fuels which have adverse effects on the environment. Waste heat from the condensing unit of refrigerating systems have been used to heat water to temperatures in the range of 40⁰C–70⁰C for domestic use with reasonable energy savings and cost [18-21].

In developing countries like Nigeria, there is a dwindling availability of fossil fuel and erratic power supply. So meeting up with water heating requirement for domestic purposes is a herculean task. It has now become imperative to find another energy source to mitigate the challenges. To this end, this research work embarks on the use of waste heat from the exhaust gases of a gasoline generator. Generators are used in Nigeria to provide electricity in homes, offices and industries

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for lighting, powering devices, appliances and machines, because of the aforementioned problems. Generator is a thermal system where a mixture of fuel and air is burnt to produce power to drive an alternator and thereby produces electricity. The burnt gases are expelled through the exhaust into the atmosphere. This work is geared towards using the generator exhaust gases to provide hot water by allowing the exhaust gases to flow through shell and tube parallel flow heat exchanger that was designed and constructed by Owojaiye(2017) in [22] shown in Figure 1.

Fig. 1. *Shell and tube parallel flow heat exchanger*

It comprises of three pipes through which the exhaust gases flow and running through a water tank which is the shell. The specifications of the heat exchanger are shown in Table 1.

Table 1. *Specifications of the shell and tube parallel flow heat exchanger*

S/N	Specifications	Quantities/Dimensions
1	Number of tubes	3
2	length of each tube	0.3 m
3	Internal diameter of tube	0.0127 m
4	External diameter of tube	0.00147 m
5	Internal shell diameter	0.18 m
6	External shell diameter	0.183 m
7	Length of heat exchanger	0.5 m
8	Capacity of the heat exchanger	0.012 m^3

2. EXPERIMENTAL SETUP

The engine used in this study was a 4-stroke, 1-cylinders, air cooled LUTIAN gasoline generator. The detailed specifications of the gasoline generator are shown in Table 2.

Table 2. *Specifications of the LUTIAN gasoline generator*

S/N	Specifications	Quantities/Dimensions
1	Model	LT3990E
2	Make	LUTIAN
3	Type	Air cooled One cylinder Four-stroke
4	Fuel capacity	15 litres
5	Rated output	3.3 Kva
6	Maximum output	3.5 Kva

The generator exhaust was coupled with the heat exchanger as shown in Figure 2. The schematic or line diagram of the experimental setup is shown in Figure 3.

Fig. 2. *The gasoline generator coupled with heat exchanger*

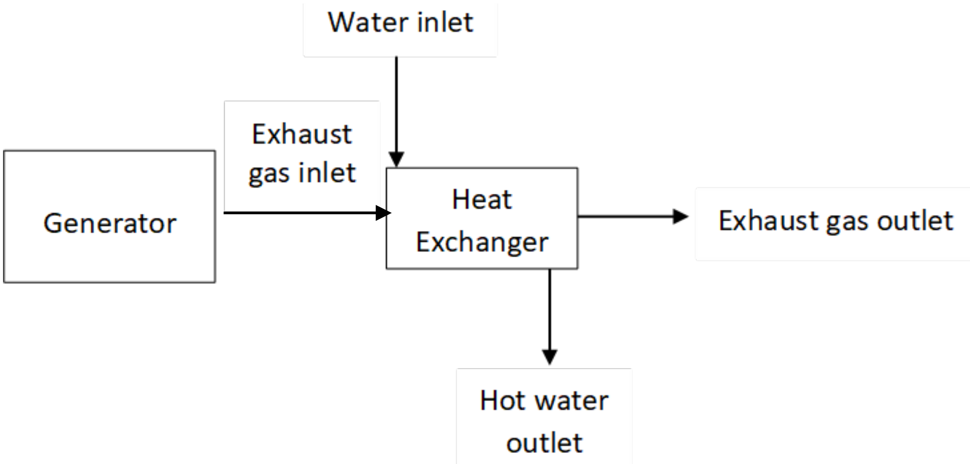

Fig. 3*. The schematic or line diagram of the experimental setup*

2.1. Experimental Run

Two cases were experimented. First, water was supplied and filled the heat exchanger (tank) without discharging through the tap. Second, water was continuously supplied to the heat exchanger and continuously discharged through the tap.

2.1.1. Test with the heat exchanger filled up and water is retained by closing the tap

The heat exchanger (tank) was filled with water and the tap was closed. The generator was put on and the inlet and outlet temperatures of exhaust gas and the temperature of water in the tank were measured with K type thermocouples after every 5 minutes. This test allowed the knowledge of the maximum period taken to heat the known quantity of water in the heat exchanger to its maximum temperature. More so, to estimate the quantity of heat required from the exhaust gases to heat the water. In order to estimate the rate at which mass of water was heated and mass flow rate of the exhaust gas, the following relations were used.

$$\dot{M}_w = \frac{\rho v_c}{t} \tag{1}$$

Where $\dot{M}_w$ is mass of water heating rate, v_c is the capacity of the heat exchanger (water tank). ρ is the density of water, t is the period of heating.

In order to estimate the mass flow rate of the exhaust gases, the energy balance equation was used, neglecting losses. That is, "heat given out by the exhaust gases = Heat gained by the water in the heat exchanger".

$$\dot{M}_e C_e (\Delta T)_e = \dot{M}_w C_w (\Delta T)_w \tag{2}$$

Where $\dot{M}_e$ is the mass flow rate of exhaust gases, C_e is the specific heat capacity of the exhaust gases. $(\Delta T)_e$ is the change in temperature of the exhaust gases, C_w is the specific heat capacity of water and $(\Delta T)_w$ is the change in temperature of water.

2.1.2. Test with water continuously supplied to the heat exchanger and water being discharged from the exchanger by opening the tap

The heat exchanger (tank) was continuously filled with water and the tap was opened. The generator was put on. The inlet temperatures of the exhaust gases and water as well as the outlet temperatures of exhaust gases and water were also measured after every five minutes with thermocouples. This allowed the estimation of the quantity of heat required from the exhaust heat to heat the water neglecting losses. In order to estimate the mass flow rate of water, after every five minutes of the experiment, the mass of water collected in the tap was weighed and divided by the time (five minutes). In order to estimate the mass flow rate of the exhaust gases, the energy balance stated in equation 2 was used. In this case $\dot{M}_w$ stated in equation 2 is called the mass flow rate of water.

3. RESULTS AND DISCUSSION

The variations of water temperature with time for filled up tank with retained water and filling up tank with discharging water are shown in figure 4 .

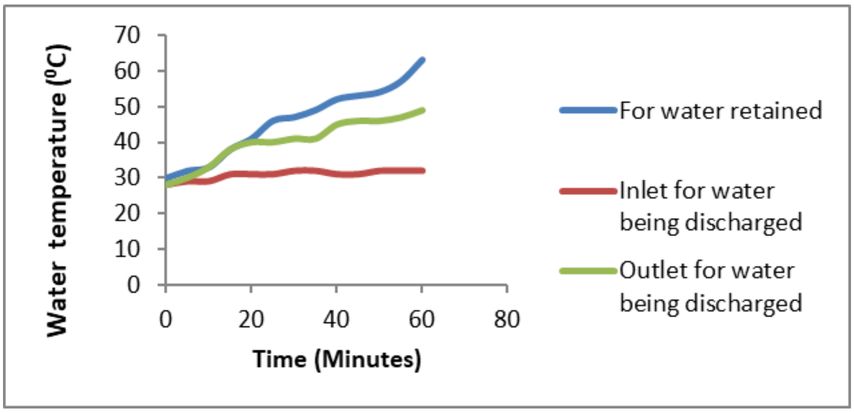

Fig. 4*. Variations of water temperature with time for filled up tank with retained water and filling up tank with water being discharged from the tank*

It can be seen from figure 4 that the temperature of the retained water in the tank, the inlet and outlet temperatures of water being discharged increased with time. However, the temperature increased more with the case of water being retained in the tank. This higher increase can be attributed to the long residence time of water to gain heat from the exhaust gases, which is the whole period of heating in the tank. During one hour of operation, the water temperature increased from 30^{0}C to 63^{0}C when the water was retained in the tank and from 28^{0}C to 49^{0}C when the water was being discharged from the tank. Figure 5 shows the variation of inlet and outlet exhaust gas temperature with time for filled up tank with retained water and filling up tank with water being discharged from the tank .

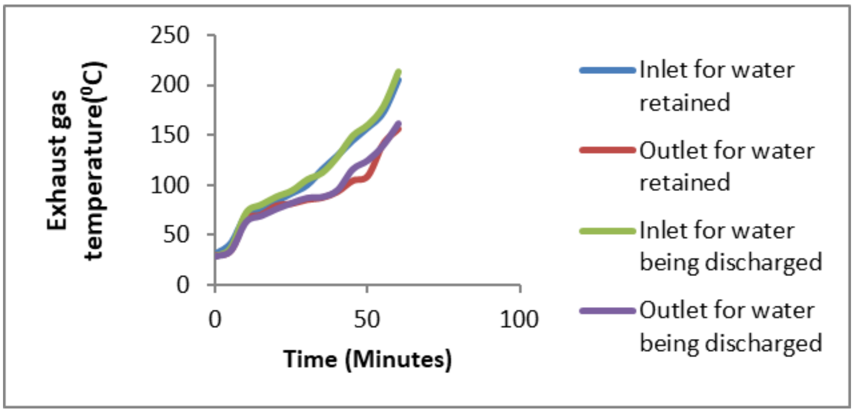

Fig. 5*. Variations of inlet and outlet exhaust gas temperature with time for filled up tank with retained water and filling up tank with water being discharged from the tank*

After five minutes of generator engine warm up and the start of the of the experiment, the inlet and outlet temperatures of the exhaust gases rose from 42^{0}C and 35^{0}C for water being retained, 37^0 Cand 34^{0}C for water being discharged to 206^{0}C and 157^{0}C for water being retained and 213^{0}C and 162^{0}C for water being discharged respectively. As it is evident in figure 5, the exhaust gas temperatures increased with increase in time of operation of the generator. The variation of mass flow rate of exhaust gases and water with time for filled up tank with retained water and filling up tank with water being discharged from the tank are shown in figure 6.

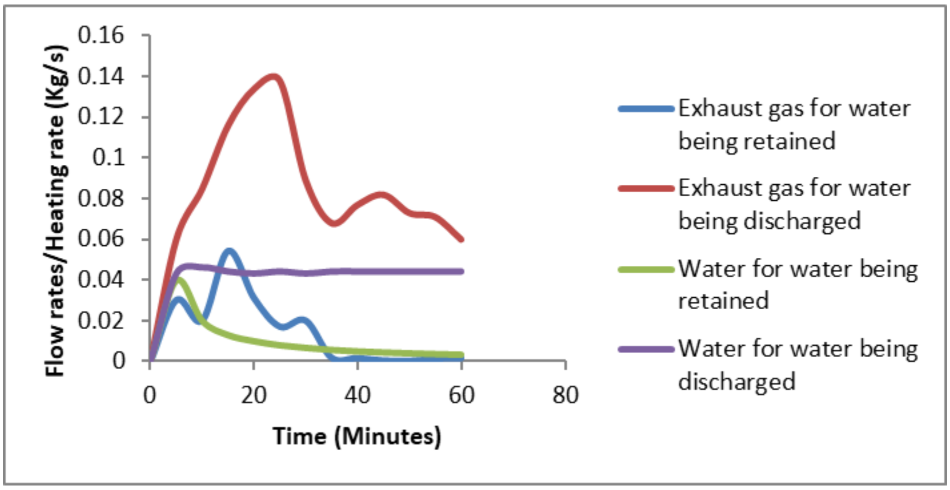

Fig. 6. Variation of mass flow rate of exhaust gases and water heating rate with time for filled up tank with retained water and filling up tank with water being discharged

The mass flow rate of the exhaust gases and water heating rate when water was retained in the tank and the mass flow rate of the exhaust gases and water when water was discharged from the tank varied considerably with time. The mass flow rate of exhaust gases and water heating rate varied around an average of 0.02 kg/s and 0.01 kg/s respectively when the tank was filled up and hot water was retained. The mass flow rate of exhaust gases and water varied around an average of 0.09kg/s and 0.044kg/s respectively. Figure 7 depicts the variation of heat gain rate with time for filled up tank with retained water and filling up tank with water being discharged from the tank.

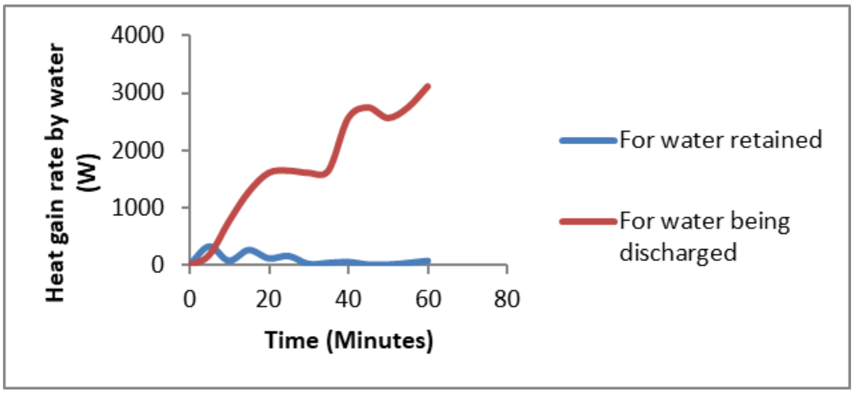

Fig. 7. Variation of water heat gain rate with time for filled up tank with retained water and filling up tank with water being discharged

The heat gain rate by water varied remarkably with time but more remarkably when the tank was filled up and water was retained than when the tank was filling up and water was being discharged, as seen from figure 7. During one hour of operation and neglecting losses the total heat gain rate for the tank being filled up and retained water and the tank filling up and water being discharged are 1.28 kW and 22.58 kW respectively

4. CONCLUSION

The use of waste heat from the exhaust of a gasoline generator through heat exchanger to heat water for household use was experimented in this research work. From the obtained results, it can be concluded that recovered waste heat from the exhaust gases of gasoline generator can heat water and raise its temperature from 30^{0}C to 63^{0}C and 28^{0}C to 49^{0}C within an hour when the heat exchanger (tank) is filled up with water, heated and the hot water is retained in the heat exchanger and when the heat exchanger is being filled up with water and the water being discharged from the heat exchanger as it is heated respectively.

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